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Education in twins and their parents across birth cohorts over 100 years:
an individual-level pooled analysis of 42 twin cohorts

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Running title: Zygosity difference in education

Abstract

Whether monozygotic (MZ) and dizygotic (DZ) twins differ from each other in a variety of phenotypes is important for genetic twin modeling and for inferences made from twin studies in general. We analyzed whether there were differences in individual, maternal and paternal education between MZ and DZ twins in a large pooled dataset. Information was gathered on individual education for 218,362 adult twins from 27 twin cohorts (53% females; 39% MZ twins), and on maternal and paternal education for 147,315 and 143,056 twins, respectively, from 28 twin cohorts (52% females; 38% MZ twins). Together, we had information on individual or parental education from 42 twin cohorts representing 19 countries. The original education classifications were transformed to education years and analyzed using linear regression models. Overall, MZ males had 0.26 (95% confidence interval (CI) 0.21-0.31) years and MZ females 0.17 (95% CI 0.12-0.21) years longer education than DZ twins. The zygosity difference became smaller in more recent birth cohorts for both males and females. Parental education was somewhat longer for fathers of DZ twins in cohorts born in 1990-1999 (0.16 years, 95% CI 0.08-0.25) and 2000 or later (0.11 years, 95% CI 0.00-0.22), compared with fathers of MZ twins. The results show that the years of both individual and parental education are largely similar in MZ and DZ twins. We suggest that the socio-economic differences between MZ and DZ twins are so small that inferences based upon genetic modeling of twin data are not affected.

Understanding how monozygotic (MZ) and dizygotic (DZ) twins differ from each other has important methodological and possible public health implications. Quantitative genetic twin models assume that MZ and DZ twins are representative of the same background population (Posthuma et al. 2003). If they are not, this may be seen as differences in the means and variances between the two zygosity groups. Zygosity differences in anthropometric measures, especially in early life, are well documented: MZ twins are lighter and shorter at birth than DZ twins (Hur et al. 2005). Furthermore, DZ twins were taller and had a somewhat higher body mass index (BMI) than MZ twins in a large international twin study based on the same database also used in the present study. The differences were largest in childhood and decreased in adulthood, where differences were less than 1 cm in height and 0.1 kg/m² in BMI (Jelenkovic et al. 2015). A Swedish study of young adult men also found that MZ twins had slightly less muscle strength than DZ twins (Silventoinen et al. 2008).

Socio-economic status (SES) is an important determinant of health (Mackenbach et al. 2008), and education is one of the most important dimensions of SES in modern societies (Hout and DiPrete 2006). Thus, the evaluation of the representativeness of SES in twins is important when generalizing the results from twin studies to the general population. One aspect of that validity assessment is to examine educational differences between MZ and DZ twins. There are at least three possible origins of differences between these two types of twins in terms of individual and parental education. First, because MZ twins tend to be shorter and lighter at birth than DZ twins (Hur et al. 2005) and these birth-related factors may be associated with slower cognitive development (Broekman et al. 2009), it is possible that differences in IQ can be found between MZ and DZ twins that could lead to differences in academic performance in later life. This is supported by findings that twins have, in general, slightly lower IQs than singletons (Voracek and Haubner 2008), and this difference is even more pronounced in triplets suggesting that there is a dose-response relationship between the birth-related anthropometrics

of multiple pregnancies and later IQ (Silventoinen et al. 2013). However, this effect can at least partially be explained by birth order as found in a Dutch study (de Zeeuw et al. 2012). There is also evidence that the multiple-birth effect on IQ has diminished over time (Voracek and Haubner 2008, Silventoinen et al. 2013), and it may not exist anymore in the most recent birth cohorts (Webbink et al. 2008, Calvin et al. 2009). Previous studies on the zygosity differences in IQ from childhood through early adulthood have shown mixed results with higher, similar and lower IQ in MZ twins as compared with DZ twins without a clear age pattern (Silventoinen et al. 2006, Haworth et al. 2009, Keller et al. 2013, Modig et al. 2011). Furthermore, the IQ difference between MZ and DZ twins was small (i.e., less than three IQ points) in the reviewed studies and thus is not likely to strongly affect academic performance.

Second, DZ twin births have become more common during the last decades in many countries because of the increasing use of in-vitro fertilization and other infertility treatments (Imaizumi 2003). A US study found that mothers who have used fertility treatments, in-vitro fertilization in particular, tend to be older, better educated and are less likely to be smokers than those mothers who have not used these treatments (Tong et al. 2016). Higher maternal age and lower smoking rate, but not higher maternal education, were also found in a Dutch study of mothers that used in-vitro fertilization (van Beijsterveldt et al. 2011), which may indicate differences in the access to in-vitro fertilization procedures between countries. It is thus possible, especially in societies where fertility treatments are not publicly funded, that the socio-economic background of parents of DZ twins has improved relative to the parents of MZ twins since the 1980s, when in-vitro fertilization first became publicly available (Steptoe and Edwards 1976).

Third, it is possible that different social dynamics between MZ and DZ co-twins may lead to different educational outcomes. A Finnish study of adolescent twins found that MZ twins reported more dependency on their co-twin, and they spend more time together than DZ twins (Penninkilampi-Kerola et al. 2005). In that study, co-twin dependence was found to be associated with less ambitious academic careers after primary education, but otherwise it is poorly known whether this would affect educational differences between MZ and DZ twins.

The previous literature reviewed above suggests that both individual and parental education may differ between MZ and DZ twins and that these differences may have changed over time. We explored these potential differences in the present study by comparing MZ and DZ twins in a very large pooled twin database that contained information on individual, maternal and paternal education from twin birth cohorts from the late 19th century through to the early 21st century.

Data and methods

The data were derived from the CODATwins (COLlaborative project of Development of Anthropometrical Measures in Twins) database described in detail previously (Silventoinen et al. 2015). The project aimed to combine height and weight data from all twin projects in the world. In addition to the anthropometric measures, the collaborators were asked to provide data on individual education for adults and parental education for children. Together, we had information on individual education from 218,482 twin individuals from 27 twin cohorts representing 15 countries. Since we were interested how the zygosity differences changed over birth cohorts, we removed those without information on birth year (104 individuals), those born before 1890 (7 individuals) and those born after 2000 (9 individuals). Thus, in the analyses, we had 218,362 twin individuals with information on

education (53% females; 39% MZ twins) including 95,208 twin pairs with information on education from both co-twins. Information on maternal education was available in 147,315 and paternal education in 143,056 twin individuals after excluding those without information on birth year (91 individuals for maternal and 89 individuals for paternal education) which came from 28 twin cohorts representing 15 countries (52% females; 38% MZ twins). These twins come from 78,748 twin families for maternal and 76,024 twin families for paternal education.

Education classifications were transformed into education years using the average length of educational level in each country. The classifications for individual education for each cohort are presented in Appendix table 1 and for maternal and paternal education in Appendix table 2. Those who reported individual (2 cases), maternal (10 cases) or paternal (7 cases) education more than 22 years were coded to have 22 years of education (i.e., equivalent of PhD education).

The data were analyzed using linear regression models with individual or parental education as the dependent variable and zygosity and twin cohort as the independent variables. We stratified the analyses by 10-year birth cohorts from 1890-1899 to 1990-1999 when analyzing individual education and to 2000 or later when analyzing maternal and paternal education. We first tested the main effect of zygosity on individual and parental education. In the analyses pooling all birth cohorts together, the results were additionally adjusted for 10-year birth cohort by including it as a classified independent variable in the regression model to also take into account possible non-linear effects of birth cohort on individual or parental education. After that we tested whether the association between zygosity and individual education is similar in males and females and whether the associations between zygosity and individual, maternal and paternal education have changed over the birth cohorts by fitting interaction terms between zygosity and sex as well as zygosity and birth cohort into the regression model. Thus, in

total, we tested four interaction effects. When individual education was analyzed, we used twin individuals after taking into account the effect of sampling twin pairs rather than unrelated individuals on standard errors by using the cluster option of Stata/SE statistical software, version 13.1 for Windows (StataCorp, College Station, TX, USA). We also replicated the analyses for 172,970 twin individuals with information on education at 30 years of age or older to confirm that the results are similar if studying completed education. Furthermore, we analyzed this between same-sex and opposite-sex DZ twins using 201,949 twin individuals for whom we knew the sex of the co-twin. When we analyzed maternal and paternal education, only one twin from each family was selected since both co-twins have the same parental education.

Since we had fewer families with information on paternal education than maternal education, we studied the representativeness of paternal education. We found that the maternal education was 0.56 (95% CI 0.47-0.66) years higher in families with information also available on paternal education as compared to families without information on paternal education, when adjusting the results for twin cohorts and 10-year birth cohorts. This suggests that in families of lower socioeconomic position, it may be more likely that we did not have information on paternal education.

Results

Figure 1 presents the mean individual, maternal and paternal education by birth cohort. The educational years increased over the birth cohorts and were higher for individual than for parental education indicating the general educational transition in the world. An exception was the cohort born 1990-1999, because in this cohort twins were generally younger and had not yet finalized their education.

Figure 1 about here

We started the analyses by studying the zygosity difference in individual education. Among both men and women, MZ twins had slightly higher education levels than DZ twins (Table 1). This difference was seen in all birth cohorts except 1890-1899 in men and 1910-1909 and 1990-1999 in women, but according to linear regression, in some birth cohorts the zygosity difference was not statistically significant because of small sample size. When data pooled according to birth year were analyzed, a statistically significant interaction effect between sex and zygosity was found ($p < 0.0001$): in men, MZ twins had 0.26 (95% CI 0.21-0.31) years more education, whereas for women this difference was 0.17 (95% CI 0.12-0.21) education years when the results were also additionally adjusted for birth cohort. However, there was also an interaction effect between zygosity and birth cohort ($p < 0.0001$ in both men and women): the education difference between twin types decreased, on average, by 0.09 years (95% CI 0.06-0.11) in men and by 0.10 years (95% CI 0.08-0.13) in women per 10-year birth cohort between 1890-99 and 1990-99. The comparisons between opposite-sex and same-sex DZ twins revealed no systematic differences, and in most of the birth cohorts the difference was non-significant (Appendix table 3). The analyses were repeated for participants 30 years of age or older using the pooled data to determine whether unfinished education affected the results. However, we found only slight changes (0.29, 95%CI 0.24-0.35 education years difference in males and 0.19, 95%CI 0.14-0.23 education years difference in females when comparing MZ and DZ twins) as compared to the results using all twins. Furthermore, birth cohort-specific results were very similar except in the two latest birth cohorts for which there were not enough participants aged 30 or older to conduct the analyses (results not shown, but are available from the corresponding author).

Table 1 about here

We then conducted similar analyses for parental education (Table 2). When data from all birth cohorts were pooled together and the results were additionally adjusted for birth cohorts, no zygosity effect was seen for either maternal (0.01, 95% CI -0.03-0.06 years more education in MZ twins) or paternal education (0.01, 95% CI -0.04-0.05 years more education in MZ twins). We found some evidence of an interaction effect between zygosity and birth cohort both for maternal ($p=0.001$) and paternal education ($p<0.0001$): the interaction term suggested that the zygosity difference in maternal education had changed 0.03 (95% CI 0.01-0.04) years and paternal education 0.05 (95% CI 0.03-0.07) years per 10-year birth cohort. In the earliest birth cohorts, there was some evidence of higher maternal and paternal education in MZ twins, and the difference was statistically significant in the cohort born 1920-1929 (0.31, 95% CI 0.13-0.48 years for maternal and 0.31, 95% CI 0.10-0.52 years for paternal education). However, this was no longer evident in the cohorts born after the 1950s. Instead, the fathers of DZ twins had higher education levels in the most recent cohorts born in 1990-1999 (0.16 95% CI 0.08-0.25 years) and 2000 or later (0.11 95% CI 0.00-0.22 years), but for maternal education we did not find a statistically significant difference.

Table 2 about here

Discussion

In this very large pooled twin study, we found that the education level of MZ twins was slightly higher than that of DZ twins. The difference was more pronounced in men and in the earliest birth cohorts, but even in these groups, the difference was quite small (less than 0.5 education years). We found some evidence of higher maternal and paternal education in MZ twins in the cohorts born in the 1950s or

earlier, but paternal education was higher in DZ twins in the latest birth cohorts (1990-1999 and 2000 or later). The higher paternal education in these birth cohorts may be associated with the increased use of fertility treatments, in-vitro fertilization in particular. US mothers using in-vitro fertilization tend to be older and better educated than other mothers (Tong et al. 2016), and this, in turn, may also have affected paternal education because of educational homogamy, which is well known in many societies (Blossfeld 2009). Also, the fertility treatment is expensive and a husband's income determinates the social position of the family in many societies, which may explain why the effect is particularly evident in paternal education.

The observation that MZ twins had slightly higher education than DZ twins is puzzling. We found some evidence of higher parental education in the earliest birth cohorts, but this effect disappeared in the later birth cohorts and even reversed for paternal education, thus not supporting the idea that the difference in individual education would be caused by socioeconomic background. It is also not very likely that physiological features related to twin pregnancies would be the explanation. MZ twins are somewhat lighter at birth (Hur et al. 2005) and slightly shorter in adolescence and adulthood than DZ twins (Jelenkovic et al. 2015). Low birthweight has been found to be associated with slower cognitive development (Broekman et al. 2009) and short stature in adulthood with lower IQ (Silventoinen et al. 2006) and less education (Magnusson et al. 2006). Thus, the zygosity differences in birth size and later height would predict an effect in the opposite direction of what was found.

One explanation for the slightly higher education in MZ as compared with DZ twins could be different social dynamics within MZ and DZ co-twins. In a Finnish study, MZ twins reported more dependence on the co-twin than did DZ twins, but this was related to selecting a vocational rather than an academic educational path after the compulsory primary education (Penninkilampi-Kerola et al. 2005). There is

also some evidence that cooperation is more common in MZ than in DZ twin pairs (Segal and Hershberger 1999, Segal 2002). More cooperation and a greater similarity in intelligence in MZ than DZ twins might help MZ twins continue schooling together. However, it is clear that more research is needed to find out whether this could explain the observed zygosity difference in education years.

Still another possible explanation of the differences in education between MZ and DZ twins could be differences in maternal age also affecting birth order. It is well known that older maternal age not only increases DZ births because of the increasing use of in-vitro fertilization but also natural DZ twinning rates (Derom et al. 2011). Thus, it is also likely that DZ twins more often have later parity than MZ twins. Older maternal age has been found to be associated with slightly lower IQ when adjusted for birth cohort effect (Myrskylä et al. 2013), and the number of older siblings also has a negative effect on education (Black et al. 2005, Brooth and Kee 2009). Because fertility has decreased during the 20th century (Lesthaeghe 2010), this effect may have become weaker as the average family size has decreased, which parallels our result on the decreasing difference in education between MZ and DZ twins over the birth cohorts.

It is also possible that selective participation may have affected our results. Higher than expected proportions of MZ twins have been found in many twin cohorts suggesting that participation rates have been higher in MZ than DZ twins (Silventoinen et al. 2015), and those in higher socioeconomic positions tend to more actively take part in surveys in general (Laaksonen et al. 2008). This may have led to the situation that DZ twins in the surveys are more socially selected than MZ twins. Selective participation due to differential mortality or disease occurrence could also explain these findings. Monozygotic twins, who are always MZ, have higher perinatal mortality than dizygotic twins (Oldenburg et al. 2012). Thus, we can speculate that the MZ twins who have both survived are more

robust and may obtain higher education levels. This may also explain the higher parental education in MZ twins born before the Second World War. Self-selection in the participating twin surveys has probably also affected our results in another way. It is unlikely that twins suffering from serious birth-related effects, such as cerebral palsy, took part in the surveys. These defects are much more common in monochorionic than in dichorionic twins (Pharoah and Dunder 2009), and the likely lower participation rates of these twins are thus more likely to create bias for MZ than DZ twins. Our results should thus be generalized primarily to the healthy twin populations without any serious birth-related complications affecting school performance.

Our data do not include information on singletons, and thus we cannot study whether twins differ from singletons according to their educational achievement. Previous studies on this issue have produced somewhat conflicting results. A Taiwanese study found that both test scores and the probability to attend college were lower in twins than singletons (Tsou et al. 2008). On the other hand, studies from Denmark (Christensen et al. 2006) and the Netherlands (de Zeeuw et al. 2012) did not find differences in educational achievement between twins and singletons, and a Swedish study found that twins had slightly better educational achievement than singletons (Hjern et al. 2012). It is thus likely that twins do not have poorer academic achievement in Western countries, but it is too early to argue whether this also applies to East Asia. Furthermore, in all of these previous studies the participants were born in the 1970s or later. Since there is clear evidence of the trend of lower IQs in twins compared to singletons in the earlier birth cohorts diminishing in the more recent birth cohorts (Voracek and Haubner 2008, Silventoinen et al. 2013), it is possible that twins have also been behind singletons in school performance in the earlier birth cohorts.

Our data have both strengths and weaknesses. Our main strength is the very large sample size allowing us to convincingly demonstrate even the very small difference in education levels between MZ and DZ twins. Such small differences would be difficult to find in any of the existing twin cohorts alone. We also had information on the maternal and paternal education of twins. It is also an advantage that we have twin birth cohorts over a period of more than 100 years, allowing us to study temporal changes of the zygosity differences. One limitation is that we do not have information on the academic performance of the twins at school; so, we do not know whether the difference in education is due to better school performance or rather continuing education with lower grades. Also, we do not have information on singletons and thus cannot say how the education of MZ and DZ twins compares to the general population. Furthermore, we do not have any information on maternal age and the number of older siblings, which may affect educational differences between MZ and DZ twins. We also found some evidence that paternal education may be selective since maternal education was higher in families where we also had information on paternal education than in families where this information was missing. Finally, pooling data from twin cohorts representing different countries and birth cohorts creates challenges when harmonizing education classifications. This is partly related to different ways to ask about education in the surveys – some cohorts have used only a few education levels, whereas others have used the exact years of education – but also reflects large differences in educational systems between countries and over time. Thus, we have focused only on education adjusted by twin cohort and birth cohort and consequently relative rather than absolute education.

In conclusion, MZ twins have slightly but systematically higher education than DZ twins, and this difference is more pronounced in men and in earlier birth cohorts. The difference is, however, so small that it is not likely to affect the comparability of MZ and DZ twins when studying the heritability of education or applying the twin design to other research questions. If this difference is regarded as a

problem, then special care should be paid to make MZ and DZ twins comparable for parity, family size, maternal age and other factors which may differ between MZ and DZ twins and in turn affect education. For parental education, we found only minor and unsystematic differences between MZ and DZ twins. Thus, our results suggest that the social background of MZ and DZ twins is largely comparable.

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Conflict of interest

None

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Figure legends.

Figure 1. Mean individual, maternal and paternal education years by birth cohort.

Table 1. Number of twin individuals and means, standard deviations (SD) and the regression coefficients (β) with 95% confidence intervals (CI) of individual education by sex, zygosity and birth cohort.

Birth cohort	MZ twins			DZ twins			Regression coefficient ¹	
	N	mean	SD	N	mean	SD	β	95% CI
Men								
1890-1899	27	5.8	3.94	41	6.6	3.81	0.32	-2.24, 2.89
1900-1909	216	9.5	4.88	353	7.8	4.41	-0.52	-1.09, 0.05
1910-1919	1585	11.7	4.16	2286	10.7	4.28	-0.41	-0.67, -0.15
1920-1929	6294	12.8	3.79	8988	11.7	4.15	-0.25	-0.39, -0.12
1930-1939	3139	11.4	4.35	7417	10.5	4.46	-0.12	-0.30, 0.07
1940-1949	6087	12.7	4.21	14297	11.5	4.40	-0.46	-0.59, -0.33
1950-1959	7496	13.2	3.64	14077	12.7	3.76	-0.26	-0.37, -0.16
1960-1969	3567	13.9	2.92	5077	13.9	2.87	-0.01	-0.15, 0.12
1970-1979	4900	14.0	2.71	5683	13.9	2.58	-0.18	-0.30, -0.06
1980-1989	3948	12.9	2.54	5117	12.7	2.47	-0.13	-0.25, -0.02
1990-1999	593	12.3	1.96	665	12.3	2.21	-0.15	-0.43, 0.12
Women								
1890-1899	57	7.5	4.15	75	5.8	2.88	-0.05	-1.39, 1.30
1900-1909	403	9.2	4.62	622	8.2	4.36	-0.17	-0.62, 0.27
1910-1919	1528	10.6	4.03	2378	9.5	4.09	0.01	-0.23, 0.24
1920-1929	3159	11.1	3.96	5428	9.9	4.02	-0.21	-0.38, -0.04
1930-1939	3988	11.3	3.95	7640	10.4	4.16	-0.24	-0.40, -0.07
1940-1949	7669	12.4	3.84	15727	11.6	4.12	-0.20	-0.31, -0.09
1950-1959	10294	13.3	3.45	15476	13.0	3.62	-0.14	-0.23, -0.05
1960-1969	6615	14.1	2.87	6948	13.9	2.85	-0.13	-0.24, -0.03
1970-1979	7124	14.5	2.88	6875	14.4	2.71	-0.13	-0.24, -0.03
1980-1989	6485	13.4	2.52	6271	13.1	2.39	-0.14	-0.24, -0.05
1990-1999	988	12.8	2.22	759	12.9	2.02	0.23	0.00, 0.47

¹Adjusted for twin cohort; MZ twins used as the reference category

Table 2. Number of twin families and means, standard deviations and regression coefficients (β) with 95% confidence intervals (CI) of maternal and paternal education by zygosity and birth cohort.

Birth cohort	MZ twins			DZ twins			Regression coefficient ¹	
	N	mean	SD	N	mean	SD	β	95% CI
Maternal education								
1890-1899	8	8.3	2.49	5	8.2	3.90	-0.05	-3.91, 3.81
1900-1909	75	9.5	2.94	96	9.0	3.03	-0.44	-1.36, 0.47
1910-1919	713	9.3	3.07	826	9.3	2.91	-0.03	-0.33, 0.26
1920-1929	2095	9.7	3.05	2459	9.5	3.00	-0.31	-0.48, -0.13
1930-1939	1267	10.4	2.69	1864	10.4	2.75	-0.08	-0.27, 0.11
1940-1949	2794	11.0	2.62	4763	11.1	2.72	-0.11	-0.22, 0.01
1950-1959	4427	11.5	2.82	6375	11.6	2.66	-0.12	-0.22, -0.03
1960-1969	1956	12.0	3.35	2478	12.6	3.00	0.10	-0.06, 0.27
1970-1979	2451	12.2	3.37	2997	12.3	3.17	0.10	-0.06, 0.26
1980-1989	3164	12.9	3.26	4319	12.6	3.50	0.06	-0.09, 0.21
1990-1999	7009	13.9	2.90	12909	14.1	2.92	0.06	-0.01, 0.14
2000 or later	4280	15.2	3.04	9418	15.3	3.18	0.06	-0.04, 0.16
Paternal education								
1890-1899	9	7.3	2.00	4	7.5	1.91	0.17	-2.44, 2.78
1900-1909	67	9.8	3.69	89	9.0	3.37	-0.82	-1.95, 0.31
1910-1919	675	9.6	3.49	800	9.5	3.47	-0.05	-0.40, 0.31
1920-1929	2018	9.7	3.65	2378	9.5	3.42	-0.31	-0.52, -0.10
1930-1939	1219	10.4	3.08	1781	10.3	3.06	-0.08	-0.30, 0.14
1940-1949	2724	11.0	3.07	4626	11.0	3.19	-0.06	-0.21, 0.08
1950-1959	4290	11.7	3.34	6224	11.8	3.24	-0.18	-0.30, -0.06
1960-1969	1869	12.8	3.66	2365	13.1	3.36	-0.05	-0.25, 0.16
1970-1979	2308	12.7	3.48	2765	12.6	3.35	0.07	-0.11, 0.24
1980-1989	2980	12.9	3.60	4090	12.5	3.88	0.08	-0.08, 0.24
1990-1999	6875	13.9	3.03	12665	14.2	3.06	0.16	0.08, 0.25
2000 or later	4114	14.8	3.34	9089	15.0	3.34	0.11	0.00, 0.22

¹Adjusted for twin cohort; MZ twins used as the reference category